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Dynamic and technological traction drive parameters optimization

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Abstract

The article considers the electric traction drive with the field regulated reluctance machine (*FRRM*). The *FRRM* operating principle and main benefits equal with induction machine and synchronous reluctance machine (*SRM*) are introduced, disadvantages are noted. Electric drive is determined as point in the static regime, transient schema analysis, which considers electrical, electromechanical and mechanical operations of electric traction drive, introduced in the first phase of optimization. The second step is expounded how a mode of increasing the velocity of the drive. The third phase is linked with the optimization *FRRM* properties with over-torque. Therefore, drive is received which meet the standards of the traction with improved weight and dimension parameters, overload capability. Weight-size characteristics optimization are evaluation the most appropriate parameters of the control system and the motor. The clarification drawing are shown in the article.

Keywords: electric traction drive, field regulated reluctance machine

1. Introduction

Electric traction drive is introduced the performance part of the facility of all electric or hybrid traction engine. Was laid on the broad band of to the power equipment, regulation system characteristics and output performance of the full electromechanical complex. As traction engine drives are often operating in heavy mode, it is need to form energy efficiency criterion of the drive in different method.

The available solutions of the electric drives based on the induction motor or *SRM* do not responding such demands. Inductions motors have the optimized structure design, coil productivity, isolation materials and power

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feed. Although, the reload value are not high. The current loading is growth and complex the *SRM* design can be achieved the nominal torque equal to 1.1 of the induction drive nominal torque [1].

A series of scientific paper are associated with the optimization of the motor element. However, the introduced solution is aimed to the bridge *m*-phase inverters supply with the bounded quantity of phases.

The fresh approach gave of the electric drive engineering for updating overload and weight-size dimension. The «valve-inverter – motor» multipurpose optimization would be done with account for specific electric traction drive requirements such as high overloads application opportunity (e.g. for outrunning or for starting with heavy goods); as minimal sizes (e.g. for urban electric transport with low floor for comfortable passenger drop-off and pick-up), by the example of the field regulated reluctance machine (*FRRM*) [2].

2. Idea and operating principles of the *FRRM*

FRRM is the synchronous reluctance machine where the stator coil can be operate as excitation coil if the winding is above the interpolar interval and it is a full step coil. Such motor is operated as the reverse *DC* machine. Stator coils can be supplied by the autonomous sources or by the usual multiphase controlled power converters, e.g. based on the full bridge circuit.

As the rotor may be made solid, high mechanical rigidity of the shaft can be reached. Drive can be done in the like stator frame as the asynchronous motor, and using the same stator line current load *FRRM* produced torque greater by 20…35 %. Because of geometric neutral is deliberated displacement to the pole edge, the drive can generate overload torque up to 4…10 nominal values [3, 7].

Although, these values would be reduced with decreasing quantity of phases of the machine. The pulsations of electromagnetic torque are coming out. The pulsations of speed as a dependent of the quantity of phases are presented on figure 1. The quantity of power semiconductor switches and total power are incremented with growth of quantity of phases. The compromise with according to the economical, mass-weight, energy value is the application of six-phase machine [4].

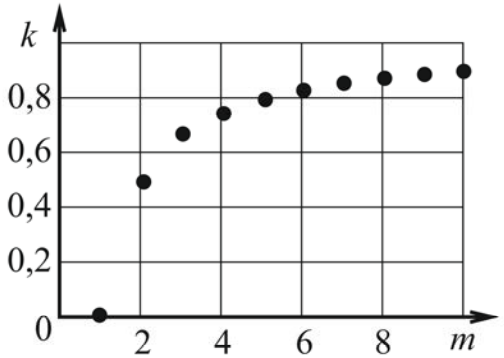

Fig. 1. Electromagnetic torque ripple rate as a function of number of phases of the *FRRM*

3. Electric drive weight-size parameters optimization

In general, the task of the weight-size characteristics optimization can be explained with the next condition:

$$q = \min \Delta P_{OV}(T_r, n_{\max}, T_{\max}),$$

where ΔP_{OV} is the electric drive power loss, T_r is the nominal motor torque, n_{max} is the high motor velocity, and T_{max} is the high drive torque.

The main limitation in this problem should be the heat engine:

$$P_{HE} = \text{const.}$$

The electric traction drive it is possible to separated velocity-torque curve into 3 part for optimizing (fig. 2, a): 1 – constant power part (*A-N-B* curve), 2 – high velocity part (horizontal part is crossing via the *A* point), and 3 – high limiting torque part (vertical part is crossing the *B* point).

If the traction drive is used, e.g. electric drive of a tractor, *A* and *B* points would be limited by the technological operation requirements – high torque is the slipping torque. If during the drive engineering, it is need to analyzing the position of the points, such characteristics of the power facilities as drive power, gear reduction rate, must be visibility. As rule, this comes if high overloads or speed broadband is hard to actualize by of electric drive [5, 15].

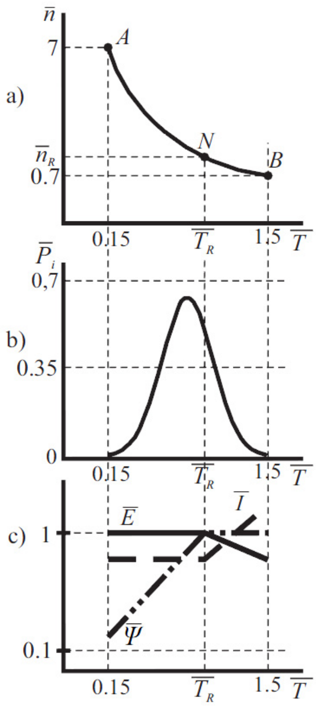

Fig.2. Drive phase motion path (a), load distribution function (b), static characteristics (c)

4. Optimization on the steady-state mode

The *A*-*N*-*B* curve (fig. 2, a) is border and it is bounded by the diesel generator power. There are two parts of the curve: *AN* – voltage *V* and current *I* are permanent values, magnetic flux is variable with the torque; *NB* – voltage *V* reduced, current *I* increases the according law:

$$P_{el} = VI = \text{const}\,.$$

The *A*-*N*-*B* curve position changes with varying the gear reduction rate. The first section can be divided on the electric traction drive with the FRRM for the basic task of better motion path selection on the task of providing maximum torque and speed of the drive. In relation to measure of minimizing the weight-size characteristics of the motor, it is worth to employ max reduction speed gear box, but it is need to correspond nominal motor velocity and instrument velocity.

Limit of heat can be introduced as next equation if the current and torque are linear graphs:

$$T_r < \sqrt{\frac{1}{T_0}\int_{t_0} T^2(t)dt},$$

where T_r is the nominal motor torque; $T(t)$ is the traction torque time curve; T_0 is the overall cycle time. Load chart for electric traction drives is traditional mounted with frequency function P_i, which is presented on fig. 1b. For each specific case this graph would be different. Employ the *NB* curve and the frequency function graph the torque *RMS* meaning can be calculated. This meaning is utilized to choose the electromechanical converter by power [6].

Velocity control by changing voltage is not effective, because the semiconductor converter power should be overvalued. For this cause, it is better to utilize operating systems with field reduction. This can decreased total capacity of the facilities to 40 percent if the considerable torque overloads would be about short time, as it is in the electric traction drive.

The location of *N* point is calculated by to criterion of electric loss minimum. The logic of switching the electric drive control system can be proposed for the first space to the second space: the diapason that has calculations of armature coil electric loss is chosen. *EMF E*, current *I*, flux Ψ are presented as an operation of torque on fig. 2, c to explain the evaluation process. This optimization algorithm can be reduced weight-size characteristics to 20% [7, 13].

5. Optimization in transient of the electric drive

The problem of definition the scheme and controller characteristics is significant, because when the drive operated close to the limited area of the speed-torque curve, self-excited fluctuation can happen by to the considerable loop fault signals.

Fig. 3 represents the electric traction drive block schema. This is a multiple circuit control system. Speed control loop *SCL* works with the drive velocity *n* which is equal to linear traction velocity v_0 in per unit. Δn_{sl} is compliance to wheelslip and is equal 0.02…0.2*n*. Torque control loop *TCL* contain of the torque controller *RT*, path current control loops *PCCL* (separated into field current control loop *FCCL* and armature current control loop *ACCL*), feedback with electrical P_{el} and mechanical P_{mech} power, real torque *T* parameters [8, 12].

The traction electric drive is supplied because of to multiple control the speed-torque curve (fig. 2, a). At that, the range of the drive a valid states is consist with single parts take into account the max velocity, heating engine power, electric drive torque, current bounds. Point *N* is matched to the electrical haulage motor nominal operating regime on the graph.

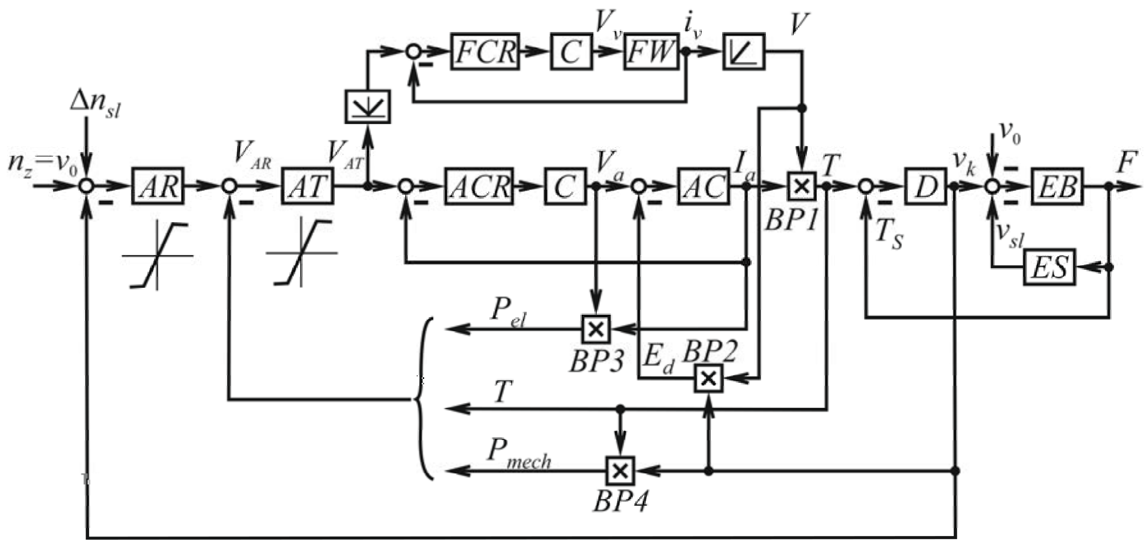

Fig. 3. Electric traction drive block diagram

The *D* element is utilized electric drive rotating inertial properties of the *SCL*. Integrating flexible element *EB* is expound the cooperation between the wheel and ground. *ES* element is determined wheel slip in operating mode and wheelskid in braking condition in feedback.

Note that the relation between wheel hauling power and slip velocity is nonlinear and nonstationary. Growth the force, accelerate the speed in the flexible slip area of every traction electric drive. Wheel and ground mechanical contact loss comes in the point *A* and the slip be present. This regime is impossible for the motor.

FCCL, *ACCL*, *MCL* are set by *PI*-regulator, external *SCL* – by the proportional regulator. System quality is calculated by the transient function. Bode diagrams are also the grade estimation [9, 11, 14].

6. Conclusion

In conclusion, the optimization results have exhibit, that the electric traction drive with the field regulated reluctance machine can achieved work out overload characteristics (up to practically) and weight-size characteristics (up to 50%). As notice demerit of the *FRRM* it should be mentioned, that pulsations of torque are around 20% of nominal *FRRM* torque and 30% of the asynchronous motor pulsations of torque. Also, the sensor of speed is needed for the operation of the drive, it's, of course, the full electric drive price growth. The *DET*-400 tractor electric drive is the commercial introduction result of the *FRRM* [6, 10].

References

[1] Yu.S. Usinin, S.P. Gladyshev, M.A. Grigoryev, A.V. Valov, A.E. Bychkov, Pulse vector control of wound rotor induction motor, SAE Technical Papers, 2010.

[2] Yu.S. Usynin, M.A. Grigor'ev, A.N. Shishkov, Electric drive with a field-regulated reluctance machine, Russian Electrical Engineering. 84(3) (2013) 149–154.
[3] M.A. Grigoryev, A.N. Gorozhankin, S.I. Kinas, E.V. Belousov, Dynamic parameters of active rectifiers, Russian Electrical Engineering. 85(10) (2014) 638–640.
[4] A.N. Gorozhankin, A.N. Shishkov, D.A. Sychev, S.I. Kinas, E.V. Belousov, A direct torque control system for synchronous electric drives, Russian Electrical Engineering. 10 (2014) 29–32.
[5] S.P. Gladyshev, Yu.S. Usinin, M.A. Grigoryev, A.N. Shishkov, A.E. Bychkov, Switching losses in the rotor of the field regulated reluctance machine, SAE Technical Papers, 2010.
[6] A.N. Shishkov, D.A. Sychev, A.E. Bychkov, N.Yu. Sidorenko, The DET-400 Tractor Traction Electric Drive, Russian Electrical Engineering. 10 (2014) 24–26. (in Russ.)
[7] Yu.S. Usinin, S.P. Gladyshev, M.A. Grigoryev, A.N. Shishkov, A.E. Bychkov, E.V. Belousov, Electric drive of an industrial tractor, SAE Technical Papers, 2013.
[8] M.A. Grigoryev, A control system for an electric drive with a synchronous reluctance machine with separate excitation, Russian Electrical Engineering. 84(10) (2013) 560–565.
[9] U.S. Usinin, M.A. Grigoriev, K.M. Vinogradov, A.N. Gorojankin, S.P. Gladyshev, Weight and dimensional parameters of a power drive for electrical vehicle, SAE Technical Papers, 2009.
[10] Yu.S. Usinin, S.P. Gladyshev, M.A. Grigoryev, A.N. Shishkov, A.E. Bychkov, The losses in control electric drives of transport mechanisms at different controlled laws, SAE Technical Papers, 2011.
[11] Yu.S. Usinin, S.P. Gladyshev, M.A. Grigoryev, A.N. Shishkov, A.E. Bychkov, K.M. Vinogradov, Pulse vector control of wound rotor induction motor, SAE Technical Papers, 2010.
[12] M.A. Grigoryev, S.I. Kinas, A mathematical model of the synchronous reluctance machine with independent control along the excitation line. Russian Electrical Engineering. 85(10) (2014) 645–648.
[13] Y.S. Usinin, M.A. Grigorjev, K.M. Vinogradov, S.P. Gladyshev, Generator for vehicle applications, based on the field regulated reluctance machine, SAE Technical Papers, 2008.
[14] M.A. Grigoryev, Specifics of power circuit arrangements of semiconductor converters for power supply to synchronous reluctance machines. Russian Electrical Engineering. 85(10) (2014) 601–603.
[15] Y.S. Usinin, M.A. Grigorjev, K.M. Vinogradov, A.N. Gorozhankin, S.P.Gladyshev, The electric drive of a tram with an average floor, SAE Technical Papers, 2008.